Technical challenges in geothermal development and production

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Summary

Geothermal energy has the potential to play an increasingly important role in the sustainable energy mix. There are, however, inherent technical challenges that need to be understood and overcome to de-risk geothermal development and production and to help accelerate commercial uptake. Previous geothermal projects provide valuable lessons learned for future development, and the oil and gas industry can offer further insights on shared difficulties. The long history of geothermal exploration and production contains abundant examples of problems of corrosion and scale, and when first encountered these often had a serious impact on project economics. Today, a range of engineering solutions have been established for these problems and can be designed into a new project from the outset. Looking forward, the geothermal fluids in sedimentary basins tend to be more benign than those in the historical volcanic-associated systems and petroleum industry experience is relevant to the types of problem and their mitigation. This paper aims to give a holistic overview of different technical challenges faced by geothermal projects globally, and to comment on areas of overlap with the petroleum industry.

Introduction

Geothermal is a renewable, baseload source of electricity and heat that can play an increasingly important role in the sustainable energy mix and progress towards Net Zero, though it is still largely underutilised globally. As growth of the geothermal industry is set to accelerate, it is increasingly important to develop these energy resources close to population centres whilst mitigating risks that may have adverse impacts on human and environment health, public perception, and project economics. Understanding potential challenges is important from an early stage, to de-risk development and to understand the implications for production. In common with oil and gas exploration and production, there are multiple geothermal play types, each associated with different ranges of technical challenges. Such challenges include risk of induced seismicity, ground deformation, gas emissions, fluid leaks, injection problems and early production decline.

The challenges vary from geothermal project to project and can broadly be placed into three categories:

1) the geological setting (relating to production from volcanic or sedimentary rocks, structural geology, lithological characteristics, and permeability),
2) the fluid characteristics (temperature and chemistry),
3) the play type and engineering technology used (conventional, closed-loop systems, Enhanced Geothermal Systems (EGS), supercritical).

Existing and historical geothermal development provide valuable lessons learned, and other subsurface industries such as the oil and gas sector, can offer further insights on shared challenges to help inform risk assessment and risk mitigation. Based on a review of published case studies and industry articles, combined with our experience in geothermal projects globally, we provide an overview and insights on some of the key technical challenges experienced in the geothermal industry.

Technical challenges in geothermal development and production

Several recent studies have addressed the risks and challenges associated with the exploration and production of geothermal resources (Gombert et al 2020, Kabeyi 2019, Schreiber et al 2016). To explore this further, data was collected from published literature and specialist articles to assess the technical geoscientific and engineering related problems encountered in individual geothermal projects. This provides a global overview of key issues that have been encountered and their impacts and mitigations.

Through rigorous compilation and standardisation, we can analyse and interpret the data and further refine the categories of key challenges. Six principal groups have been identified (Figure 1):

- Infrastructure damage
- Productivity problems
- Health safety & environment
- Inadequate resource
- Injectivity problems
- Drilling problems

The primary recorded problem events are induced earthquakes, surface deformation, flow decline and temperature decline. Less commonly reported problems include gas emissions, excessive injection pressure, insufficient permeability, blow-out, fluid leaks, corrosion, well collapse and drilling fluid losses. Many of these issues can be attributed to insufficient characterisation of the reservoir, reservoir management strategy (relating to extraction and injection) and intrinsic fluid and lithological characteristics.

Analysis of encountered technical challenges can offer further insights into understanding the subsurface. Combining these recorded challenges with other data such as well data, reservoir properties and resource estimates (Figure 2) and underlying geological factors (including but not limited to

structural setting, lithological, fluid chemistry and seismicity data), can help to predict potential problems for unexplored or underexplored areas with limited available data.

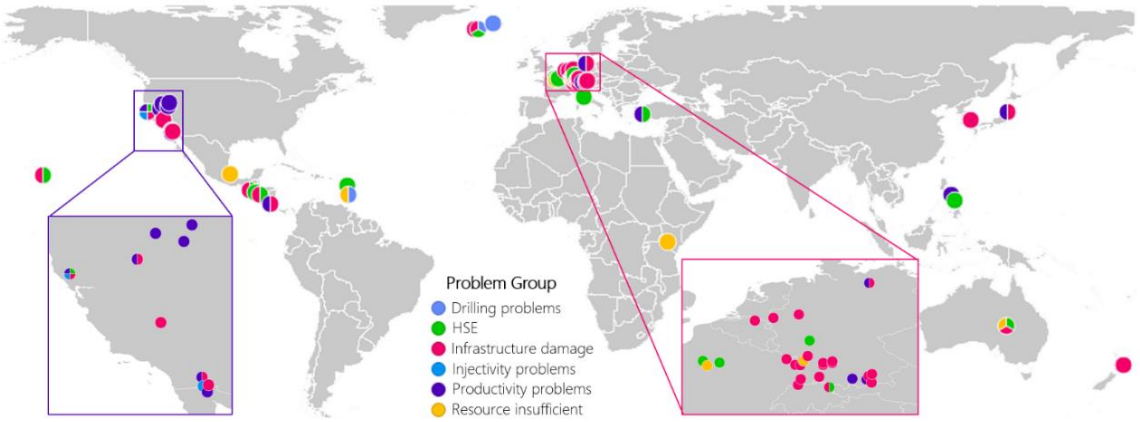

***Figure 1**: Overview of technical challenge groups identified in geothermal projects globally.*

***Figure 2**: Global subsurface and above-ground data key to geothermal resource exploration and development, which includes technical challenges encountered in geothermal projects.*

How do challenges vary between different geothermal systems?

Geological settings

Certain problems are more applicable to particular geological settings. For example, volcanic hosted geothermal systems can contain geothermal fluids with high gas concentrations (CO_2, CH_4, SO_2, H_2S, NH_3) which need to be properly processed. Carbonate hosted systems can contain high levels of CO_2 requiring mitigation treatments. Sedimentary systems may be susceptible to issues such as ground deformation associated with swelling or dissolving of certain lithologies (e.g. clays or evaporites) in the event of a subsurface fluid leak. Reduction of reservoir pressure can induce subsidence, particularly above relatively shallow reservoir ash-rich volcanic systems. The structural setting and stress regime can have implications particularly for seismicity risk; areas of complex tectonics and/or critically stressed faults require careful consideration and modelling when planning geothermal developments.

Fluid flow rates and reservoir temperatures determine the power output of a geothermal resource. Understanding the matrix and/or fracture permeability is key to modelling the reservoir response and production sustainability.

Fluid characteristics

Geothermal fluid chemistry varies with geological setting, temperature, and pressure of the reservoir. The fluids can contain high concentrations of minerals and toxic gases that may cause significant

challenges for geothermal production, such as scaling (e.g. silica, calcite, sulphides) and corrosion issues; particularly when the geofluids flash to stream either in the wellbore or in the geothermal plant. Formation damage is also a potential problem that can be caused by reinjection. Potential adverse impacts on human and environmental health requires that fluid handling is carefully designed throughout exploration, production and disposal. Fluid chemistry related problems need to be effectively managed through operation strategy, well design, material selection and chemical treatments.

Play type and engineering technologies
Different play types and associated engineering technologies have implications for different challenges. For example, current and historical EGS projects (Figure 3) by design induce seismicity through high injection pressures and/or cooling to create fractures in deep crystalline basement, but the specific location and magnitude of the resulting seismicity can be difficult to predict. The risk of induced seismicity in shallow sedimentary doublet systems is low but changes in pressure during drilling, or changes in temperature during circulation of fluids can trigger seismicity in rocks sensitive to changes in stress state.

In multilateral closed-loop systems (Figure 3) the working fluid is passed through pipework, in contrast to conventional hydrothermal systems which target geofluids flowing through the reservoir rock. These systems are relatively recent innovations and problems associated with insufficient or declining flow rates, aggressive fluid chemistries or ground deformation (due to reservoir drawdown) are not predicted to be relevant in projects that use this technology. The challenge in this type of system is to ensure the temperature of the circulating fluid is maintained.

The development of very high temperature supercritical geothermal resources, such as in the Iceland Deep Drilling Project, is novel and offers huge potential energy resources, but these settings are particularly challenging due to the high temperatures and aggressive fluid chemistries. Projects which have targeted (or accidentally encountered) supercritical fluids have experienced drilling, completions, and fluid handling challenges. Mitigation of these issues depends on continued technological advancements in drilling at high temperature and pressures whilst also withstanding corrosion and scaling.

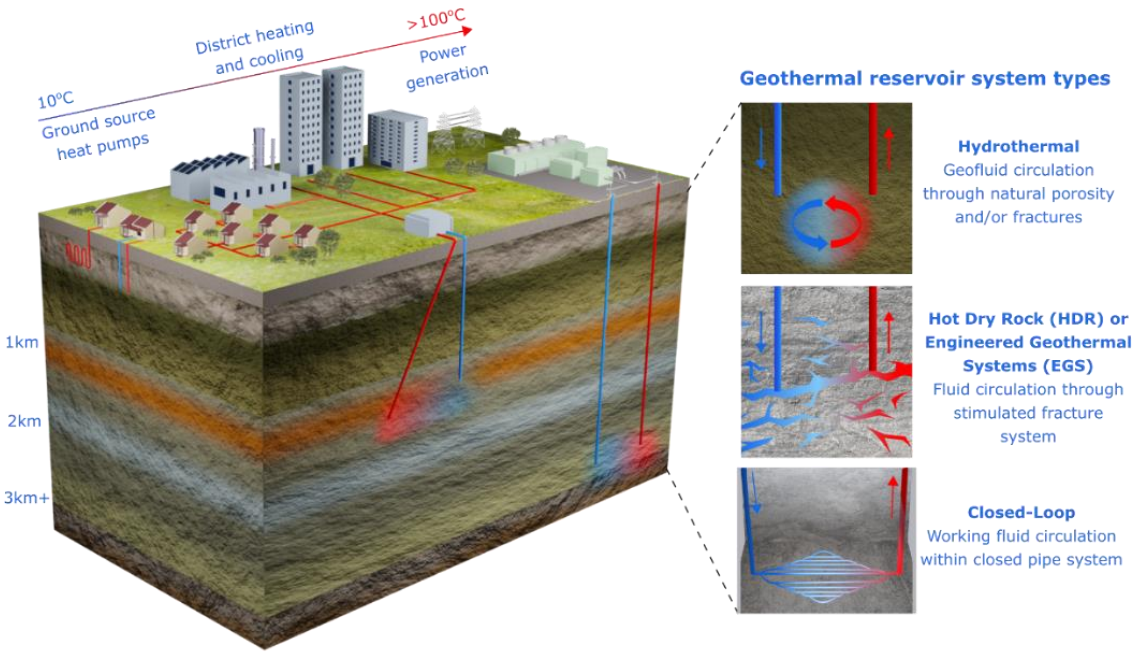

***Figure 3**: Schematic of different geothermal system types and technologies used. Technical challenges can vary based on the aforementioned factors.*

Comparison with oil and gas

Many problems that are encountered in geothermal are attributed to subsurface development in general and are therefore also applicable to the oil and gas industry. Risk of induced seismicity is a shared challenge in both industries. Blow-outs are generally a higher risk in hydrocarbon exploration/production compared to geothermal (Gombert et al 2020). Drilling issues, such as drilling fluid losses and well collapse, occur in both geothermal and oil and gas development. Oil and gas industry experience of drilling wells, particularly in deep sedimentary settings and in offshore locations, can offer expertise to mitigate risk in these potential geothermal growth areas. Reservoir pressure maintenance is of concern for both geothermal and hydrocarbon reservoirs, including the potential for associated ground deformation. The experience gained during hydrocarbon production of injectivity performance in different reservoir geological scenarios will benefit geothermal, as the targeting of sedimentary resources continues to expand. Although there are inherent differences between the fluids produced in geothermal compared to oil and gas, production and injection of water becomes an important issue in the later life of a hydrocarbon field, as a result, fluid chemistry challenges are shared by both industries.

Mitigation of these issues involves reservoir modelling, optimised well planning and fluid handling strategies; both industries can benefit from shared lessons learned.

Conclusions

Prediction and management of technical challenges is key to reliable and economic delivery of geothermal energy. Knowledge of the subsurface geology is key to understanding the potential challenges, and to reduce uncertainty in evaluating and managing geothermal resources. Geoscience and engineering data, combined with knowledge of technical challenges, provides useful insights into risk mitigation and trends relating to geological setting, reservoir characteristics and exploitation methods. In this light, the ability to analyse innovatively the large volumes of subsurface geoscience and engineering data generated globally in the geothermal and petroleum industries will help set the scene for urgently needed geothermal investment decisions over the coming decade.

References

Gombert, P., Lahaie, F., Cherkaoui, A., Contrucci, I. and de Santis, F. [2020]. Main Risks Related to Deep Geothermal Energy in the World. In: Proceedings World Geothermal Congress, Reykjavik, Iceland, 26 April – 2 May.

Kabeyi, M. J. B. [2019]. Geothermal Electricity Generation, Challenges, Opportunities and Recommendations. International Journal of Advances in Scientific Research and Engineering, 5(8)

Schreiber, S., Lapanje, A., Ramsak P. and Breembroek, G [2016]. Operational issues in Geothermal Energy in Europe: Status and Overview. Operational issues in Geothermal Energy in Europe, Reykjavík, 93.